Investigating Lesser Flamingo *Phoeniconaias minor* movements and the potential connectivity among regional populations using satellite-telemetry

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Examiner les mouvements du Flamant nain *Phoeniconaias minor* et la connectivité potentielle parmi les populations régionales en utilisant des balises argos. Le Flamant nain *Phoeniconaias minor* est considéré comme « Quasi Menacé » parce que ses populations semblent subir une diminution modérément rapide de leurs effectifs. Le Plan d'Action international pour la Conservation du Flamant nain estime que la dégradation des habitats de reproduction et de nourrissage de l'espèce constitue la menace la plus importante. Une des actions prioritaires est de déterminer la délimitation et les mouvements des populations en utilisant des balises argos. En mai 2009, la Vogelwarte Radolfzell de l'Institut ornithologique Max-Planck, Allemagne, à entamé un projet pour étudier les mouvements des Flamants nains à l'aide de balises argos, en munissant quatre flamants de balises au Lac Abijatta, Ethiopie. En juin 2009, 15 autres Flamants nains ont été équipés de balises au Lac Bogoria, Kenya. Les données de haute qualité transmises par les balises pendant les premières semaines du projet permettent d'espérer que des découvertes concernant l'écologie des mouvements du Flamant nain vont être faites pendant les années à venir.

Summary. Lesser Flamingo *Phoeniconaias minor* is classified as Near Threatened because its populations appear to be undergoing a moderately rapid reduction. The International Single Species Action Plan for the Conservation of the Lesser Flamingo identifies the degradation of the species' breeding and feeding habitats as the most critical threat. One of the actions given high priority in the action plan is to determine population delineation and movements using satellite tracking to determine movements between lakes, interchange and possible gene flow between populations, and site usage. In May 2009, the Vogelwarte Radolfzell at the Max-Planck Institute for Ornithology, Germany, commenced a project to investigate the movements of Lesser Flamingos by satellite telemetry, by tagging four Lesser Flamingos with solar-powered GPS platform transmitter terminals (PTT) at Lake Abijatta, Ethiopia. In June 2009, 15 additional Lesser Flamingos were equipped with PTTs at Lake Bogoria, Kenya. During the first weeks of the project the PTTs transmitted high-quality data indicating that in the next few years the project will reveal new insights into the ecology of Lesser Flamingo movements.

Lesser Flamingo *Phoeniconaias minor* is the smallest and most numerous flamingo species in the world (Childress *et al.* 2008) and, like all flamingos, is a habitat specialist. Lesser Flamingos depend on shallow saline alkaline wetlands in which they forage mainly on blue-green algae and benthic diatoms (Ridley *et al.* 1955, Tuite 1979, 2000). There are four distinct regional populations in Africa and Asia. Childress *et al.* (2008) list 69 key sites, i.e. sites regularly holding >1% of a regional population, but regular successful breeding has been confirmed at only six (Fig. 1). Due to their declining populations, Lesser Flamingos are categorised as Near Threatened in the 2009 IUCN Red List of Threatened Species (BirdLife International 2009). The species is also listed in columns A and B of the Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA) Action Plan, Appendix II of the Bonn Convention and Appendix II of the CITES convention (Childress *et al.* 2008).

There are three distinct regional populations of Lesser Flamingo in Africa. The world's largest concentration, of an estimated 1.5–2.5 million individuals, representing >75% of the global population (Wetlands International 2006), occurs on soda lakes in the East African Rift Valley (Brown *et al.* 1982, Mlingwa & Baker 2006). However, during the past 50 years regular breeding of this population has been recorded only at Lake Natron, Tanzania (Bartholomew & Pennycuick 1973, Brown *et al.* 1982, Childress *et al.* 2008). Historically, Lesser Flamingos were also recorded breeding at Lake Nakuru, Kenya, with the last reliable record in 1915 (Meinertzhagen 1958). Irregular sporadic breeding events have also been recorded at a few other sites, such as Lake Turkana, Kenya, in 1957, Lake Magadi, Kenya,

Figure 1. Distribution of Lesser Flamingos *Phoeniconaias minor* (from Childress *et al.* 2008).
Répartition du Flamant nain *Phoeniconaias minor* (d'après Childress *et al.* 2008).

in 1962 (Brown & Root 1971) and Lake Abijatta, Ethiopia, in 2005, when successful breeding of the Lesser Flamingo was recorded for the first time in the latter country, and a crèche of 2,500–3,500 chicks was observed (Bozic & Ewnetu 2008).

A smaller regional population occurs in southern Africa, with an estimated 55,000–65,000 individuals (Wetlands International 2006). This population increases during good breeding years e.g. *c.*80,000 breeding pairs were counted at Sua Pan, within the Makgadikgadi, Botswana, in 2000, and *c.*85,000 individuals were present there in March 2005 (Childress 2005). It has been speculated that numbers breeding at Sua Pan may be augmented by birds from countries not comprehensively included in southern African population counts, like Angola and Mozambique, or indeed from further afield (G. McCulloch pers. comm.). Frequent breeding occurs at Sua Pan, Botswana, and less frequently at Etosha Pan in Namibia (Simmons 1996, Borello *et al.* 1998, McCulloch & Borello 2000, McCulloch & Irvine 2004). Historically, sporadic breeding with many fewer individuals involved was also reported from Zambia (Brown 1957), and since 2007 birds have bred annually on a specially constructed island in Kamfers Dam, Kimberley, South Africa, which colony produced *c.*9,000 chicks in 2007/2008 (Anderson 2008, Childress *et al.* 2008). In 2008/2009 almost 15,000 chicks were counted (M. Anderson pers. comm.). Lesser Flamingos, thought to be younger individuals, are well known for attempting to breed at many sites each year, given suitable local conditions. However, these attempts usually involve few pairs (< 500) and are almost invariably unsuccessful.

A small population of 15,000–25,000 Lesser Flamingos occurs in West Africa (Wetlands International 2006), with the main concentrations in the Senegal Delta and its environs (Trolliet & Fouquet 2001). 'Large' concentrations are also found at coastal sites in northern Mauritania (Isenmann 2006) and in Guinea, with up to 10,000 individuals (Trolliet & Foquet 2001).

Breeding has rarely been reported in West Africa. A colony of *c.*800 nests was discovered in 1965 in southern Mauritania (de Naurois 1965). In the same area a breeding attempt involving *c.*200 nests failed in 1988, apparently due to disturbance by local hunters (Lamarche 1988). Concentrations of juveniles and displaying by larger groups of adult Lesser Flamingos led repeatedly to speculations that there might be undiscovered breeding sites in West Africa (Dugan 1984, Hamerlynck & Messaoud 2000, Diawara *et al.* 2008).

In South Asia, Lesser Flamingos occur at a variety of mostly coastal sites between Yemen and Bangladesh (Mundkur 1997, Childress *et al.* 2006), and in the saline wetlands of Gujarat and Rajasthan states in north-west India. The Asian population is apparently either subject to extreme fluctuations or the majority spend their time at sites not visited by ornithologists during censuses. Because of the remoteness of the sites used by the species in India, a complete census has been difficult to obtain. The best current estimate is 390,000 individuals (Wetlands International 2006). Regular breeding is only reported from several sites in Gujarat in north-west India, with a maximum of *c.*10,000 pairs (Parasharya & Tere 2006). Sporadic breeding has also reported in the Indian state of Rajasthan (Kumar 1996) and unsuccessful breeding attempts have been reported in Yemen (Al-Saghier & Porter 1996).

Intra-population movements of Lesser Flamingos

Lesser Flamingos generally make regular nomadic movements between breeding and non-breeding sites depending on breeding and feeding conditions. Seasonal migration takes place when large numbers move from non-breeding feeding areas to the breeding sites when those sites become suitable for breeding (e.g. when large pans flood in southern Africa and India). These movements can involve distances of several hundred kilometres (Childress *et al.* 2007).

In eastern Africa, the numbers of Lesser Flamingos at certain sites can vary by several tens of thousands of birds (Vareschi 1978, Tuite 1979, 2000, Mlingwa & Baker 2006). On individual lakes, their numbers can double or be reduced by half within the period of a week. Lesser Flamingos are adapted to respond to changes in local environmental conditions by moving

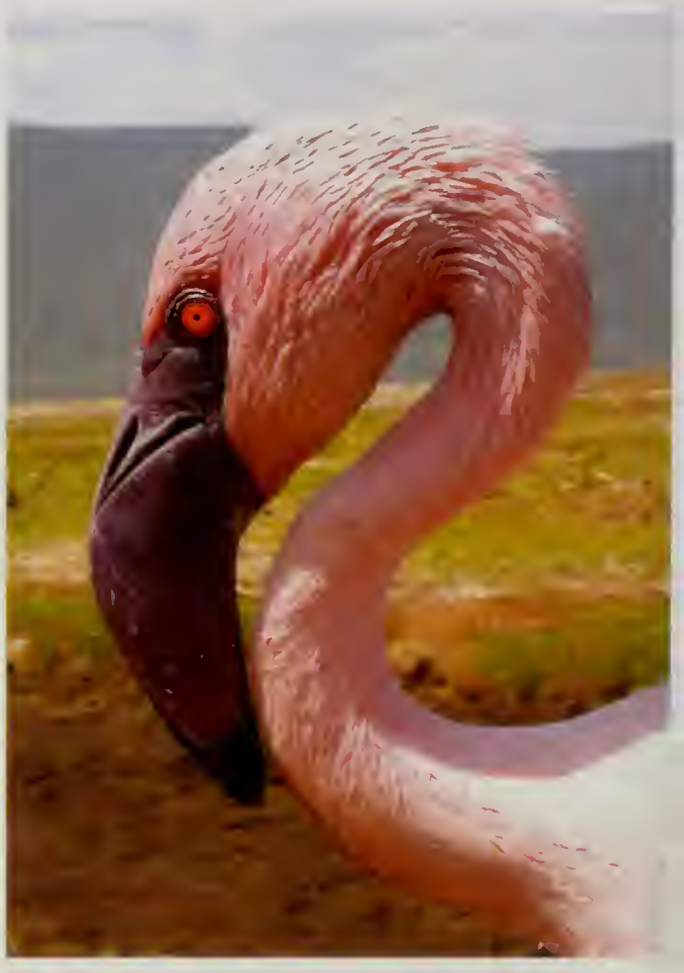

Figure 2. Lesser Flamingo / Flamant nain *Phoeniconaias minor*, Lake Bogoria, Kenya (Volker Salewski)

elsewhere, and thus depend on a network of sites (BirdLife International 2000). In 1969, for example, 960,000 Lesser Flamingos were counted on just two lakes, Nakuru and Bogoria in Kenya (Bartholomew & Pennycuick 1973). Between 1974 and 1976, the number of Lesser Flamingos recorded on nine lakes in the Rift Valley of East Africa was much lower (between 430,000 and 540,000: Tuite 2000). The location of the 'missing' flamingos was unknown but an association with relatively high numbers of Lesser Flamingos in southern Africa was discussed (Tuite 1979, see below). However, the 'missing' birds might also be explained by the fact that the lakes were not counted concurrently, the censuses having been conducted over a period of several months.

Eight Lesser Flamingos were equipped with satellite transmitters in Kenya in 2002/03. One of these transmitters failed shortly thereafter, but the remaining seven birds were followed for up to four years (BC unpubl.). The flamingos moved independently with varying flight directions and distances as well as varying stopover periods at

Figure 3. Lesser Flamingos *Phoeniconaias minor* flying over Botswana (Graham McCulloch)
Flamants nains *Phoeniconaias minor* volant au dessus du Botswana (Graham McCulloch)

Figure 4. Lesser Flamingos *Phoeniconaias minor* bathe in a freshwater spring, Lake Bogoria, Kenya (Volker Salewski)
Flamants nains *Phoeniconaias minor* se baignant dans une source d'eau douce, Lac Bogoria, Kenya (Volker Salewski)

Figure 5. Waiting for the Lesser Flamingos *Phoeniconaias minor*; basic research camp at Lake Abijatta, Ethiopia (Volker Salewski)

Attendant les Flamants nains *Phoeniconaias minor* ; le camp des chercheurs au Lac Abijatta, Ethiopie (Volker Salewski)

Figure 6. A Lesser Flamingo *Phoeniconaias minor* is equipped with a satellite transmitter (Volker Salewski)

Un Flamant nain *Phoeniconaias minor* est équipé d'une balise (Volker Salewski)

Figure 7. A Lesser Flamingo *Phoeniconaias minor* takes off after being equipped with a satellite transmitter (Volker Salewski)

Un Flamant nain *Phoeniconaias minor* s'envole après avoir été équipé d'une balise (Volker Salewski)

different lakes. There was no clear pattern of the birds choosing to stay at specific lakes and it was often the case that one of the tagged birds would depart from a lake within days of another arriving at the same site. The entire flyway for all tagged flamingos consisted of a 940 km north–south range in the Rift Valley between Lake Logipi, Kenya, and Lake Bahi, Tanzania (Childress *et al.* 2007).

Within southern Africa, Borello *et al.* (1998) and Childress (2006) discussed indications for extensive movements of Lesser Flamingos, such as highly fluctuating numbers in some areas, erratic breeding events in high concentrations at different sites, and observations of migrating birds. On Sua Pan in Botswana, five Lesser Flamingos were equipped with satellite transmitters of which two failed shortly after they were fitted. The remaining three birds stayed for several months at the original site until the lake dried out. During the movements that followed their departure from Sua Pan, south into South Africa, distances of up to 930 km were covered within a few days (McCulloch *et al.* 2003).

In West Africa, scarcely anything is known about the movements of Lesser Flamingos. The initiation of breeding in favourable environmental circumstances (de Naurois 1965, Lamarche 1988), the large fluctuations in the number of birds in the Senegal Delta from *c.*100 to 50,000 individuals (Trolliet & Fouquet 2001), as well as the surprising discovery of up to *c.*10,000 Lesser Flamingos in Guinea (Altenburg & van der Kamp 1991) indicate wide-ranging movements within this population. In Asia, the wide distribution of the species with only few breeding sites is also indicative of extensive movements. Seasonal fluctuations are regularly recorded in India (Parasharya & Tere 2006).

Causes of movements within populations

There are few studies investigating the causes of movements in Lesser Flamingos. There was a significant correlation between the density of algae small enough to be filtered by Lesser Flamingos and Lesser Flamingo numbers between December 1972 and 1974 at Lake Nakuru, Kenya (Vareschi 1978). At the same site, Tuite (2000) also found that over many months between 1974 and 1976, the number of Lesser Flamingos was positively associated with the density of the filamentous

blue-green algae *Arthrospira fusiformes* (formerly *Spirulina platensis*), the main food of the species in East Africa. In this study, the number of Lesser Flamingos on Lake Nakuru declined from over one million individuals in January 1974 to less than 30,000 in August of the same year, following a distinct decline of *Arthrospira* in the first half of that year. *Arthrospira* densities show irregular fluctuations, for unknown reasons. Some peaks last for several years and the biomass can then reach values of more than ten times the mean density. Tuite (2000) associated these fluctuations in their main food type with the distribution of Lesser Flamingos on the lakes in the East African Rift Valley. However, according to Vareschi (1978) there is no positive correlation between the algal density at different lakes and their flamingo numbers.

Changes in fresh water availability, lake water conductivity and disturbance by humans or predators were considered unlikely to cause population fluctuations (Vareschi 1978).

The studies using satellite tags on Lesser Flamingos in East Africa revealed a non-significant trend showing that individual staging periods were correlated with local precipitation (Childress *et al.* 2007). In southern Africa, Borello *et al.* (1998) discussed the possibility that movements of Lesser Flamingos are associated with the movement of the Intertropical Convergence Zone. Erratic breeding at Sua Pan appears also to be associated with high rainfall (Borello *et al.* 1998) and Lesser Flamingos arrive at the breeding sites within days of their flooding (McCulloch & Irvine 2004). For West Africa, Hamerlynck & Messaoud (2000) describe the coincidence of high rainfall with the occurrence of Lesser Flamingos in the Senegal Delta. For India, Parasharya & Tere (2006) also mention that numbers of Lesser Flamingos vary with the inundations of the River Rann in the Rann of Kachchh. All these studies suggest a connection between the numbers of Lesser Flamingos and the availability of food resources and/or the suitability of breeding sites, but individual decisions during non-breeding movements between feeding sites, whilst probably linked to food availablity are still little understood.

Movements between populations

There is only one record of a Lesser Flamingo moving between two regional populations: a bird that was ringed as a chick in Kenya in 1962 was found dead in the Western Sahara in 1997 (Childress & Hughes 2007). Apparent parallel fluctuations in the sizes of regional populations of Lesser Flamingos have been discussed as an indication that migrations between regional populations exist (Borello *et al.* 1998, Simmons 1996, 2000).

In southern Africa, the unexpected high numbers of Lesser Flamingos in November 1974 at Sua Pan, coinciding with a decline in numbers in eastern Africa, suggested migration between these two regional populations (Vareschi 1978, Borello *et al.* 1998). Furthermore, that Lesser Flamingos show fat deposition like other migrants was seen as being indicative that the birds could move between southern and eastern Africa (Simmons 2000). On the other hand, counts revealing unexpected high numbers of Lesser Flamingos in southern Africa could indicate that residents are more numerous than previously thought, which could explain high breeding densities without immigration from eastern Africa (Childress 2006). A coordinated census was conducted in this region in 2008, but the results have yet to be reported.

It is unknown whether the Lesser Flamingos observed regularly in Madagascar, where breeding has never been recorded, originate from eastern or southern Africa. Their occurrence in Madagascar, together with records on some Indian Ocean islands, has led to speculation about movements between Africa and India via island hopping (Borello *et al.* 1998). For India, Parasharya & Tere (2006) also suggested possible immigrations into the subcontinent because of incredible concentrations during the breeding season.

None of the birds equipped with satellite tags in Botswana and Kenya moved out of their regional areas (McCulloch *et al.* 2003, Childress *et al.* 2007). However, a recent molecular study comparing the populations of eastern and southern Africa indicated that there is some gene flow between them, thereby supporting the hypothesis of at least restricted interchange between the two populations (Zaccara *et al.* 2008).

Investigating Lesser Flamingo movements for science and conservation

One of the key questions in animal ecology is how environmental heterogeneity and the spatial distribution of resources influence the distribution

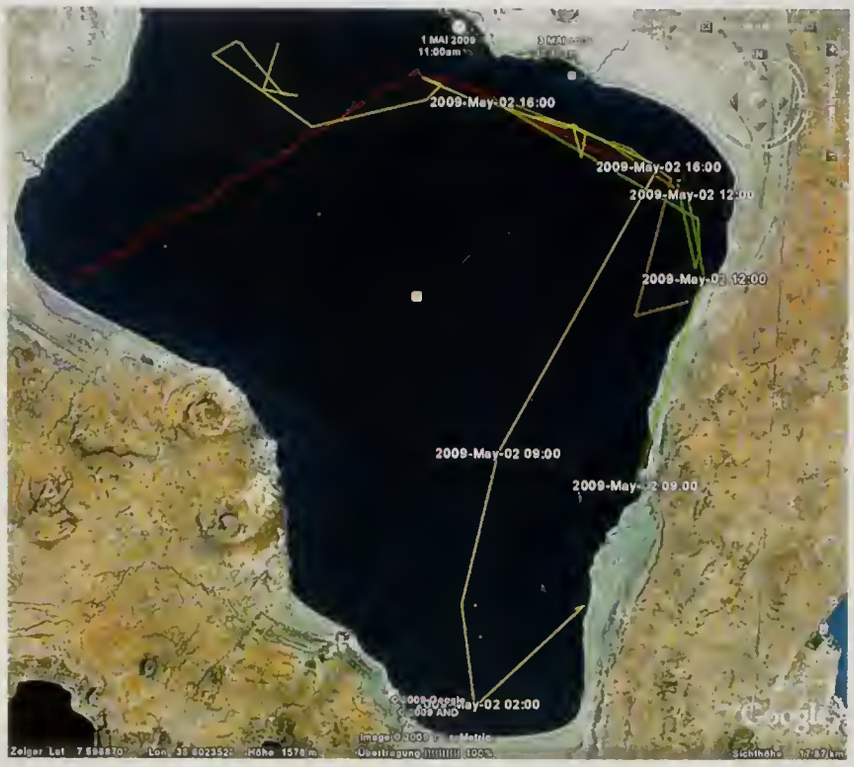

Figure 8. Movements of four Lesser Flamingos *Phoeniconaias minor* equipped with satellite tags at Lake Abijatta, Ethiopia, in May 2009.

Les mouvements de quatre Flamants nains *Phoeniconaias minor* équipés de balises au Lac Abijatta, Ethiopie, en mai 2009.

of individuals in space and time. The selection of temporary staging sites plays a key role in the life of mobile organisms, e.g. for reproduction, predator avoidance or optimal foraging, because in general resources are not evenly distributed either spatially or temporally. Highly mobile organisms like birds can cover relatively large distances to exploit resources, but these movements are also related to costs like increased mortality or decreased physiological condition, with negative effects, e.g. on predator avoidance or reproduction. Individual decision-making processes therefore possess direct fitness consequences and are the basis for the evolution of certain traits with respect to movements. There are, however, few studies that investigate whether movements of birds mainly reflect the distribution of resources or whether there are different individual decision-making rules that control their movements. Lesser Flamingos perform erratic long-distance movements between extremely patchily distributed foraging sites that also show large, probably unpredictable, fluctuations of resources over time. Furthermore, the species uses very few sites for reproduction within its huge geographical range and breeding success is strongly related to unpredictable climatic events. Therefore, Lesser Flamingos are an ideal species to study decision-making processes in connection with animal movements. Studying the movements of Lesser Flamingos will reveal important insights into the biology of the species and will add to our understanding of the processes related to the ecology of animal movements in general.

Understanding the movements of Lesser Flamingos has a direct applied aspect concerning the conservation of the species because the reliance of the global population on patchy habitat makes the species very vulnerable when disturbances at a few key sites occur. Apart from natural fluctuations in resources (Tuite 1979, 2000) and unpredictable conditions at some of the breeding sites, there are anthropogenic threats to key sites. Vareschi (1978) mentioned already that the effluent from Nakuru's sewage plant could contaminate Lake Nakuru, especially since potentially dangerous industries were built. The only breeding site of the East African population, Lake Natron, which is unprotected, is currently threatened by plans for soda extraction facilities (Childress *et al.* 2008). Nocturnally, migrating Lesser Flamingos are reported to be killed at powerlines far from their usual feeding and breeding sites in southern Africa (Borello *et al.* 1998, Simmons 2000). In West Africa, Lamarche (1988) reported that the second known breeding attempt of this regional population apparently failed because of disturbance by local hunters. For India, Parasharya & Tere (2006) described hunting for meat consumption and egg collection as important threats, the latter being the sole cause for the failure of regular breeding attempts at Purabcheria. Furthermore, collisions of Lesser Flamingos with utility structures are so frequent at some sites that local fisherman patrol the respective areas in the morning to collect the victims. Childress *et al.* (2008) suggested that the most critical threats to Lesser Flamingos are the degradation of their breeding and feeding habitats through altered hydrology and water quality, wetland pollution, extraction of salt and soda ash, and the disruption of their breeding colonies by human activities. The aim of the

recently published International Single Species Action Plan for the Conservation of the Lesser Flamingo (Childress *et al.* 2008), is to improve the conservation status of Lesser Flamingo from Near Threatened to Least Concern, by seeking to ensure that all major breeding and feeding sites are designated as protected areas, maintained in a good ecological condition and that breeding colonies are not disturbed, amongst other measures. The action plan therefore emphasises that 'a high priority action for the conservation of the species is to determine population delineation and movements by conducting satellite tracking . . . to determine movements of individuals between lakes, interchange and possible gene flow between populations and site usage.'

A new study to investigate movements of Lesser Flamingos and potential connectivity between populations

The Vogelwarte Radolfzell at the Max-Planck-Institute for Ornithology, Germany, was involved in the first satellite-tracking studies to investigate movements of Lesser Flamingos in the Rift Valley of eastern Africa (Childress *et al.* 2004, 2007). In a new project, 50 solar-powered GPS satellite platform transmitter terminals (PTT) were made available. These PTTs will enable individual birds to be followed for several years through the ARGOS system (Toulouse, France). The data will be stored in www.MoveBank.org and can be consulted there or in Google Earth. The intention was to distribute the PTTs among the West African (10–15 PTTs), East African (15–20 PTTs) and Indian populations (20–25 PTTs) respectively. Funding for more transmitters is currently being sought to include the southern African population. The objectives of the study are:

- to investigate movements of Lesser Flamingos within the regional populations;
- to investigate environmental conditions associated with movements;
- to detect important staging areas;
- to discover possible unknown breeding sites, e.g. in West Africa;
- to investigate whether there are movements between the four regional populations;
- to discover routes if movements between populations occur;
- to assess the importance of different staging areas;
- to assess threats during the movements and at important staging areas;
- to initiate conservation strategies at important staging areas and new breeding sites;
- to raise public awareness through contacts with various media and local organisations;
- to gain publicity by an internet link to follow the flamingo movements;

Field work commenced in early May 2009 when three adult male and one adult female Lesser Flamingos (sexing method based on Childress *et al.* 2005) were equipped with GPS satellite transmitters at Abijatta-Shalla Lakes National Park in Ethiopia using the methods described by Childress *et al.* (2007). Data sent by the transmitters showed that all four birds stayed in the park during the period immediately following capture. In early June, one bird moved in a non-stop nocturnal flight of 530 km north-northeast to Lake Abbe, on the Ethiopian / Djibouti border, followed by a second individual in early July. This had been the hypothesised direction and flight path for any connection between the East African and Indian populations.

In June 2009, 15 additional Lesser Flamingos were equipped with GPS satellite transmitters at Lake Bogoria, Kenya. One of the PTTs stopped working on Lake Nakuru after ten days. The same direction was followed by seven other birds during the first four weeks after they were equipped with the PTTs, which made their way either to Lake Nakuru, Lake Elmentaita or to both in succession. Additionally, two flamingos chose to fly even further, to Lake Natron in northern Tanzania, the only known regular breeding site of the East African regional population. One of these birds returned north again after three days to Lake Nakuru, whilst the other continued south to Lake Manyara. The solar-powered GPS PTTs produced data of much higher quality than previous transmitters using the Doppler effect, and it is expected that during the next three to four years the PTTs will reveal many more interesting movement patterns leading to a better understanding of the species' movements and ecology, as well as helping to implement new conservation strategies.

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